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Mobile-Assisted Case-Based Learning to Promote Creative Cognitive Flexibility and Deep Understanding in Physics

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Abstract

Developing creative thinking in physics requires instructional approaches that encourage students to apply multiple problem-solving strategies and representations in authentic contexts. However, evidence on how mobile-assisted case-based learning promotes creative cognitive flexibility remains limited. This study investigated the contribution of mobile-assisted case-based learning to students' creative cognitive flexibility as an indicator of deep conceptual understanding of ideal gas concepts. An explanatory sequential mixed-methods design was employed involving 70 undergraduate students who participated in a mobile-supported case-based learning intervention delivered through smartphones and a learning management system. Quantitative data were collected using pretest–posttest assessments of cognitive flexibility, while qualitative evidence was derived from students' written responses to examine shifts in reasoning strategies and representational use. The findings indicate meaningful improvements in students' creative cognitive flexibility following the intervention, accompanied by predominantly positive learning interest. Qualitative analyses further revealed that students became more capable of employing multiple solution pathways, integrating mathematical, graphical, and conceptual representations, and critically reflecting on the assumptions underlying ideal gas models. These findings suggest that mobile-assisted case-based learning provides an effective learning environment for fostering adaptive reasoning, strengthening deep conceptual understanding, and promoting creative thinking in undergraduate physics education. The study contributes empirical evidence supporting the integration of mobile technologies with authentic case-based pedagogy to advance higher-order thinking in digital science learning.

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INTRODUCTION

Creative thinking has emerged as an essential competency in twenty-first-century education, as students are increasingly required to address complex, open-ended problems that cannot be solved through a single procedural approach (Galeboe et al., 2025; Hilda et al., 2020; Puspita et al., 2025). In physics education, students are expected not only to master fundamental concepts but also

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to integrate diverse knowledge structures, employ multiple representations, and develop alternative problem-solving strategies (Irwandani, 2021; Nurkasma et al., 2022). According to Torrance (1966), creative thinking encompasses four key dimensions: fluency, flexibility, elaboration, and originality. Among these dimensions, flexibility occupies a particularly important role because it reflects students' ability to shift between problem-solving strategies, utilize multiple forms of representation, and examine problems from different conceptual perspectives. Such capabilities are fundamental for developing adaptive reasoning and deep conceptual understanding in physics learning contexts (Ersoy & Ozcan, 2026; Heymann, 2003).

Current evidence suggests that physics instruction in higher education remains largely characterized by concept memorization and teacher-centered lecture practices (Alfi & Tralisno, 2026). Such conditions limit opportunities for students to generate creative ideas, explore alternative approaches, and evaluate multiple solution pathways (Kennedy et al., 2025). Consequently, students often become reliant on a single problem-solving procedure and demonstrate limited capacity to shift strategies or perspectives when confronted with unfamiliar problems (Meidina & Dewi, 2026). This lack of cognitive flexibility highlights the need for instructional approaches specifically designed to cultivate flexibility as a core component of creative thinking.

Case-based learning (CBL) offers considerable potential for addressing students' limitations in developing cognitive flexibility, as it is grounded in authentic cases that require learners to analyze complex situations, evaluate alternative solutions, and integrate concepts within meaningful contexts (Miller et al., 2025). In physics education, the conceptual and representational nature of topics such as the relationships among pressure, volume, and temperature necessitates the use of multiple representations—including mathematical, graphical, and particulate forms—as well as adaptive shifts in problem-solving strategies Laciak et al., 2022). Consequently, the implementation of CBL in physics instruction is particularly relevant and may contribute directly to the development of students' cognitive flexibility (Ar et al., 2024; Salinas-Navarro & Palma-Mendoza, 2026. Furthermore, the use of authentic cases enables students to connect theoretical concepts with real-world phenomena, thereby fostering the development of higher-order thinking skills that are both transferable and applicable across diverse contexts (Anandhi et al., 2023; Jiménez et al., 2024).

This study positions cognitive flexibility as a central dimension of creative thinking because it reflects students' ability to adaptively employ multiple strategies and representations when understanding concepts and solving contextual problems (Marsellinda et al., 2025;. Cuifolo et al., 2023). Within the Understanding by Design framework, deep understanding is demonstrated through the ability to view concepts from multiple perspectives, connect ideas across contexts, and apply principles to novel situations (Wiggins & McTighe, 2005). Consistent with this perspective, cognitive flexibility enables learners to generate alternative approaches and transfer knowledge adaptively across different representations and contextual settings (Miller et al., 2025; von Thienen et al., 2023). Such capabilities are indicative of deep understanding because students move beyond rote recall and are able to apply concepts flexibly in diverse contexts (Schlott, 2024). Despite its importance, previous research has shown that science students often rely on convergent responses to routine tasks and encounter difficulties when required to generate alternative solutions to non-routine problems (Suherman & Vidákovich, 2022; Wirnoto & Ratnaningsih, 2022). These findings highlight the need for instructional approaches that not only assess creative outcomes but also facilitate the development of underlying creative thinking processes in a more profound and meaningful manner (Görlich, 2026; Long et al., 2022; Österholm et al., 2025).

Although case-based learning (CBL) has considerable potential to foster cognitive flexibility through the analysis of authentic cases, its implementation is often constrained by limited instructional time and classroom interactions, restricting opportunities for students to fully explore alternative strategies and representations. The integration of mobile technology, therefore, becomes essential for extending access to learning materials, case scenarios, and collaborative discussions beyond conventional classroom boundaries. Recent advances in mobile technology have created new opportunities for implementing CBL in more flexible and accessible ways. Mobile-assisted learning enables students to access learning resources anytime and anywhere while sustaining their engagement in processes of analysis, reflection, and knowledge construction (Guo et al., 2024; Kukulska-Hulme & Shield, 2008; Muflihah et al., 2025; Riadi et al., 2024; Salim et al., 2026). Within this context, a mobile-based Learning Management System (LMS) serves not only as a platform for content delivery but also as a digital environment that captures students' learning traces, enabling researchers to examine patterns of cognitive flexibility throughout their problem-solving processes(Hafid et al., 2022; Hasanah, 2023; Mahabu et al., 2025). Previous studies further suggest that the integration of case-based learning with digital technologies contributes positively to both learning outcomes and students' overall learning experiences (Bucheli et al., 2024; Hakim & Abidin, 2024; Simbolon, 2022; Usman et al., 2020).

Previous studies have demonstrated the effectiveness of case-based learning (CBL) and mobile learning as separate instructional approaches; research integrating these two approaches to explore students' creative thinking processes in depth—particularly the dimension of cognitive flexibility—remains limited. Most existing studies have focused primarily on learning outcomes, providing only a partial understanding of the underlying processes through which creative thinking develops. Accordingly, this study aims to examine patterns of students' creative cognitive flexibility through the implementation of mobile-assisted case-based learning and to analyze the distribution of students' learning interests within a digital physics learning environment. The findings are expected to extend the current literature on innovative instructional strategies in physics education and provide both conceptual and practical foundations for the development of more effective learning models in the digital era.

METHOD

Research Design

This study employed an explanatory sequential mixed-methods design, integrating quantitative and qualitative analyses to examine students' creative thinking patterns, with particular emphasis on flexibility as an indicator of deep understanding. This design was selected because quantitative findings alone were insufficient to explain the diversity of strategies and representations students employed when solving case-based problems (Toyon, 2021). Qualitative analysis of students' responses was used to interpret and elaborate the quantitative results by revealing how students adapted strategies, integrated concepts, and utilized multiple representations. Consequently, the qualitative findings provided explanatory insights into the patterns identified quantitatively, offering a more comprehensive understanding of students' creative cognitive flexibility.

Participant and Learning Context

The participants comprised 70 undergraduate students from the 2023 cohort of the Science Education Program at Universitas Negeri Surabaya, all of whom were female. Participants were selected through purposive sampling based on their active engagement in the learning process. The study was conducted in a General Physics course focusing on ideal gas concepts. This sampling approach was employed to ensure that all participants had sufficient exposure to the instructional intervention, thereby providing data that were closely aligned with the study objectives. However, selecting participants based on active engagement may introduce sampling bias; therefore, the findings should be interpreted with caution and are not intended for broad generalization. All participants completed the intervention in its entirety, from pretest to posttest. Ethical approval for the study was obtained from the Science Education Program at Universitas Negeri Surabaya. Before participation, all students provided informed consent, and their involvement was entirely voluntary.

Learning Intervention

The instructional intervention was conducted over four sessions, each lasting 150 minutes, using mobile-assisted case-based learning (CBL) delivered through a Learning Management System (LMS). Each session consisted of case orientation, individual analysis, small-group discussion, whole-class discussion, and reflection. The cases were designed around ideal gas concepts situated in authentic real-world contexts. The LMS, accessed via smartphones, facilitated the distribution of learning materials, case access, discussion forums, assignment submission, and formative feedback throughout the intervention. During the individual analysis phase, students identified problems and generated potential solutions independently before engaging in collaborative discussions to compare alternative problem-solving strategies and conceptual representations. The instructor acted as a facilitator by providing scaffolding through guiding questions, conceptual clarification, discussion prompts, and feedback on students' arguments, thereby supporting the development of cognitive flexibility.

Instruments

The study employed two instruments: a creative thinking skills test and a learning interest questionnaire. Creative thinking skills were assessed using six case-based open-ended questions on ideal gas concepts, developed to measure the flexibility dimension of creative thinking. Responses were evaluated using an analytic rubric on a 0–4 scale, where 0 indicated an irrelevant response, 1 reflected a single simple idea, 2 represented two underdeveloped ideas, 3 indicated several relevant solutions with reasonably clear explanations, and 4 reflected multiple solutions supported by accurate scientific explanations. The total possible score ranged from 0 to 24. Each item required students to analyze ideal gas phenomena using diverse problem-solving approaches and representations. Assessment was guided by an analytic rubric encompassing variation in solution strategies, shifts in conceptual perspectives, the use of multiple representations, and the ability to transfer concepts across contexts.

Content validity of the creative thinking test was evaluated by five physics education experts using Aiken's V, yielding coefficients ranging from 0.67 to 0.87, indicating that all items met the minimum acceptability threshold for a panel of five validators. Items with values approaching the lower threshold were revised based on expert feedback, particularly regarding item clarity, alignment with the flexibility construct, and the appropriateness of the case context for ideal gas concepts. Following revision, all items were deemed suitable for use in the study. Inter-rater reliability was high, with a Cohen's Kappa coefficient of 0.78. Learning interest was measured using a 12-item questionnaire adapted from the Four-Phase Model of Interest Development. The instrument employed a four-category scale (Interested, Moderately Interested, Less Interested, and Not Interested) to assess students' interest, engagement, and attention during the learning process. Content validity was similarly confirmed by five experts, while internal consistency demonstrated good reliability, with a Cronbach's alpha coefficient of 0.82.

Data Collection Procedure

Data collection was conducted in three stages. First, a pretest was administered to establish students' baseline creative thinking profiles. Second, participants engaged in a series of mobile-assisted case-based learning activities on ideal gas concepts over multiple instructional sessions. Third, a posttest was administered to assess changes in creative thinking skills, followed by the completion of a learning interest questionnaire. In addition, all students' written responses submitted through the LMS were collected and analyzed to identify patterns of cognitive flexibility as an indicator of deep conceptual understanding.

Data Analysis

Data were analyzed using both quantitative and qualitative approaches. Quantitative data, consisting of creative thinking scores, were categorized using the median split technique to classify students into high- and low-performance groups at each measurement point. Pretest (33) and posttest (85) median values were calculated separately to account for shifts in score distributions following the instructional intervention. The use of different median thresholds was intended to reflect students' relative positions within the group distribution at each stage of measurement. However, interpretations of changes in creative thinking skills were based primarily on individual raw score differences between the pretest and posttest, whereas median-split categorization served as a descriptive tool for examining the distribution of student performance before and after the intervention. Pretest–posttest category transitions were analyzed using McNemar's test to examine changes in paired categorical data. Scores on the flexibility dimension were analyzed using the Wilcoxon signed-rank test to determine differences before and after the implementation of mobile-assisted case-based learning, accompanied by effect size estimates (r). In addition, learning gains were evaluated using normalized gain (N-gain) analysis to assess improvements in students' flexibility following the intervention.

The distribution of students' learning interests was examined using a chi-square goodness-of-fit test by comparing the observed proportions with the institutional benchmark distribution (40–30–20–10). Qualitative data, consisting of students' written responses, were analyzed through thematic coding to identify patterns in problem-solving strategies, representational use, and conceptual integration. The qualitative findings were subsequently integrated with the quantitative results during the interpretation phase, providing a more comprehensive understanding of students' creative cognitive flexibility.

RESULTS AND DISCUSSION

Before the intervention, students accessed the institutional academic portal (Siakadu–Sidia) and logged into the Learning Management System (LMS) via their smartphones to obtain instructional materials, authentic case scenarios, and discussion forums. The LMS served as an academic interaction platform that enabled students to analyze cases, submit responses, and receive formative feedback. Mobile access provided opportunities for students to revisit case materials and revise their arguments, thereby fostering cognitive flexibility in understanding ideal gas concepts. The case tasks were designed in alignment with the dimensions of Explanation, Application, Perspective, and Self-Knowledge to promote deeper conceptual understanding. The LMS interface is presented in Figure 1.

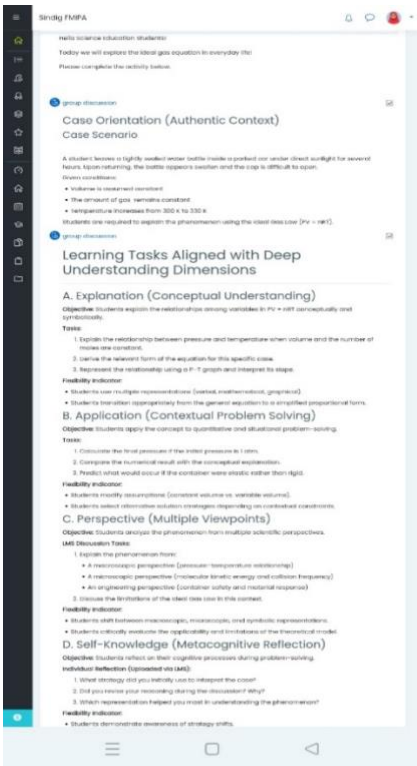

Figure 1. LMS in Mobile (Smartphone)

The analysis involved 70 students who participated in mobile-assisted case-based learning on ideal gas concepts using smartphones and the institutional LMS. Creative thinking scores were categorized into Low and High groups using the median split method (pretest = 33; posttest = 85). As presented in Table 1, 30 students remained in the High category, 20 transitioned from Low to High, 10 remained in the Low category, and 10 shifted from High to Low. To examine category transitions in paired data, McNemar's test was employed. The results indicated that the observed changes were not statistically significant ($\chi^2 = 3.33$, $p = 0.068$), although a positive trend was evident, with more students moving from the Low to the High category than vice versa. These findings suggest a tendency toward improved cognitive flexibility following the implementation of mobile-assisted case-based learning. However, the non-significant McNemar result indicates that the observed category shifts cannot be interpreted as statistically significant changes in performance levels.

Accordingly, the transitions are more appropriately viewed as descriptive evidence of improvement rather than conclusive evidence of significant categorical advancement.

Table 1. Shift in Creative Thinking Skills Categories (Flexibility) Before and After Intervention

	Posttest Low	Posttest High	Total
Pretest Low	10	20	30
Pretest High	10	30	40
Total	20	50	70

To analyze the increase in students' creative thinking flexibility, a comparison of pretest and posttest scores was conducted using descriptive statistics and the Wilcoxon signed-rank test. The results of the analysis are shown in Table 2.

Table 2. Descriptive Statistics and Wilcoxon Signed-Rank Test Results on Flexibility Indicators

N	Pretest Mean (SD)	Posttest Mean (SD)	Mean Difference	Z	p-value	Effect size (r)
70	2.15 (0.67)	3.13 (0.69)	0.98	-4.85	<0.001	0.58

Analysis of students' creative thinking flexibility scores revealed a notable improvement following the implementation of mobile-assisted case-based learning. The Wilcoxon signed-rank test indicated a statistically significant difference between pretest and posttest scores ($Z = -4.85$, $p < 0.001$). Mean scores increased from 2.15 ($SD = 0.67$) to 3.13 ($SD = 0.69$), representing a gain of 0.98 points. The calculated effect size was large ($r = 0.58$), suggesting that the intervention exerted a substantial impact on the development of students' cognitive flexibility. Furthermore, normalized gain (N-gain) analysis yielded a value of 0.53, which falls within the moderate category. This result indicates that mobile-assisted case-based learning was moderately effective in enhancing students' flexibility in understanding and applying ideal gas concepts.

Mobile-assisted case-based learning was associated with shifts in students' creative thinking categories, although these changes did not reach statistical significance. Of the 70 participants, 30 remained in the high category throughout the intervention, indicating stable performance among students with strong initial competencies. In addition, 20 students (28.6%) progressed from the low to the high category following the intervention, whereas 10 remained in the low category and 10 students (14.3%) transitioned from high to low. These findings suggest a positive developmental trend, although the observed changes were gradual and not fully reflected in categorical classifications. The results further indicate that students with lower initial abilities may require additional support through structured scaffolding, explicit conceptual guidance, and repeated contextual practice to foster cognitive flexibility (Awi et al., 2025). This interpretation is consistent with prior research demonstrating that regulated scaffolding can enhance academic performance and self-regulated learning strategies, particularly among students with lower prior achievement (Azevedo & Hadwin, 2005; Vygotsky, 1980). Moreover, interaction-based scaffolding has been shown to reduce cognitive load and strengthen self-regulation in digital learning environments, thereby supporting more effective engagement with complex learning tasks (Chang & Yang, 2023).

These findings are consistent with prior research indicating that pedagogical interventions aimed at fostering higher-order thinking skills often yield only small to moderate shifts in pre–post categorical classifications, even when statistically meaningful improvements in average performance are observed (Loyens et al., 2023). Similar trends have been reported in studies of Project-Based Learning and STEAM education, where improvements in achievement scores are evident, yet substantial transitions from lower to higher performance categories occur relatively infrequently (Safriana et al., 2022). Such findings suggest that the development of higher-order cognitive competencies is typically gradual and incremental rather than characterized by abrupt categorical change. Accordingly, the present findings provide evidence that case-based learning positively contributes to the enhancement of students' creative thinking skills, particularly the flexibility dimension. Nevertheless, the relatively limited movement among students in lower performance categories highlights the need for differentiated instructional support and targeted scaffolding to maximize learning gains among learners with lower initial levels of performance. The distribution of students' learning interest categories following the implementation of mobile-assisted case-based learning is presented in Figure 2.

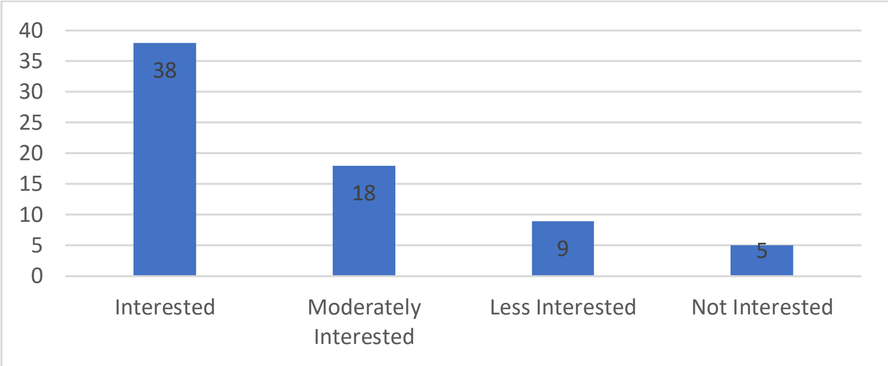

Figure 2. Distribution of Learning Interest

Figure 2 illustrates the distribution of students' learning interest following the implementation of mobile-assisted case-based learning. Most students were classified as Interested or Moderately Interested, whereas only a small proportion fell into the Less Interested and Not Interested categories. A chi-square goodness-of-fit test revealed a significant difference from the expected distribution ($\chi^2(3)$ = 29.76, $p < 0.001$). The expected proportions (40–30–20–10) were used as a descriptive benchmark based on the Four-Phase Model of Interest Development and the instructional goal of achieving predominantly positive learning interest after the intervention. These findings should be interpreted cautiously as descriptive evidence of learning interest patterns. Overall, the results suggest that mobile-assisted case-based learning not only supports deeper understanding through cognitive flexibility but also enhances students' affective engagement in the learning process.

The increase in learning interest suggests that mobile-assisted case-based learning not only influences students' flexibility but also strengthens their affective engagement in the learning process (Agusnaya et al., 2024). The high proportion of students demonstrating positive learning interest indicates that mobile access through the LMS creates a learning environment that is more interactive, reflective, and contextually relevant (Nurita et al., 2025). Such conditions allow students to engage actively in collaborative discussions, explore multiple problem-solving approaches, and continuously reflect on their conceptual understanding. This finding is consistent with previous research indicating that case-based learning not only promotes deeper conceptual comprehension but also enhances student engagement and motivation. Furthermore, instructors have reported that this approach is effective in fostering student motivation and facilitating meaningful participation in interactive small-group discussions, thereby creating a more learner-centered educational environment (Arifah & Nur, 2025). More broadly, meta-analytic evidence on active learning in STEM education has demonstrated significant improvements in academic performance alongside reductions in student failure rates, suggesting the creation of a more engaging and supportive learning environment (Ko, Y., Choi, Y., 2022). These findings strengthen the argument that case-based learning (CBL), particularly when integrated with mobile technology support, holds considerable potential for enhancing student engagement, learning interest, and creative thinking skills in the context of physics education.

The results of the chi-square goodness-of-fit test demonstrated a statistically significant discrepancy between the observed distribution of learning interest and the predefined target distribution 40–30–20–10% ($\chi^2(3)$ = 29,76; p < 0,001). Students' learning interest levels did not fully conform to the expected distribution, although descriptive findings indicated that the majority of students were classified within positive interest categories following the instructional intervention. From a theoretical perspective, these findings are consistent with the Four-Phase Model of Interest Development, which posits that interest can be triggered and sustained through the provision of relevant learning tasks and supportive social-instructional environments. Some students appeared to progress toward more developed and stable phases of interest, as reflected in the high proportion of students categorized as Interested, whereas others still required continued and more intensive support to maintain and strengthen their interest (Magdalena et al., 2021). The CBL literature further highlights the importance of case-based sense-making as a mechanism for connecting theoretical knowledge with real-world applications. Such an approach not only promotes deeper conceptual understanding but also contributes to the maintenance and development of students' learning interests. By engaging students in authentic and meaningful learning experiences, CBL enhances the perceived relevance of course content, thereby fostering greater engagement and sustained interest in learning. These findings are consistent with prior research demonstrating the effectiveness of case-based learning in promoting both student engagement and learning motivation (Agistiningsih et al., 2023).

The presence of students in the Less Interested/Not Interested category highlights the need for more adaptive learning support. Research on scaffolding underscores the importance of contingent assistance that responds to learners' immediate needs, the gradual fading of support as competence increases, and the progressive transfer of learning responsibility from instructors to students. Such an approach may help sustain engagement and promote greater autonomy among students with lower levels of learning interest (Pol et al., 2015). This strategy is effective when implemented adaptively within small-group learning settings, as is commonly practiced in case-based learning (CBL). In this context, differentiated interventions such as formative feedback, tiered contextual assignments, and role rotation during case discussions have the potential to move students from the Less Interested/Not Interested category to the Moderately Interested/Interested category (Jürges et al., 2011; Lundborg et al., 2021).

These findings align with recent meta-analytic evidence suggesting that active learning approaches not only enhance overall learning outcomes but also contribute to narrowing achievement disparities among student groups with diverse academic backgrounds and prior levels of competence (Qadri, 2026). Accordingly, a well-designed and consistently implemented mobile-assisted case-based learning approach has the potential to sustain high levels of learning interest among the majority of students while fostering greater engagement among those with initially lower interest levels, thereby supporting more equitable participation without exacerbating engagement disparities (Lundborg et al., 2021).

Thematic analysis was conducted through a systematic process of open coding, axial coding, and categorization of students' written responses. The coding process focused on indicators of cognitive flexibility, including the use of diverse mathematical procedures, the ability to shift across representations, the integration of multiple gas laws, and reflection on the limitations of the ideal gas model. To enhance the reliability of the analysis, two researchers independently coded the data and achieved a high level of agreement (Cohen's Kappa = 0.81). Any discrepancies in coding were resolved through discussion until consensus was reached. The qualitative findings were further supported by excerpts from students' responses. For example, one student not only applied relevant equations but also connected them to Charles's Law and Gay-Lussac's Law when explaining changes in pressure and volume within an authentic case context. In addition, the qualitative results were presented through a joint display that linked themes of cognitive flexibility with improvements in quantitative scores, thereby providing a more comprehensive interpretation of the development of students' creative thinking skills. The patterns of students' cognitive flexibility in understanding ideal gas concepts identified through the thematic analysis are presented in Table 3.

Table 3. Student Flexibility Patterns in In-Depth Understanding on the Ideal Gas Concept

Dimension	Indicator Flexibility	Conceptual Meaning	Frequency	Example Student Responses
Explanation	Adaptation of solution strategiy	Understanding of P–V–T relations	32	I use another method by comparing changes in pressure and temperature
Application	Transfer of representation	Integration Mathematical - physical	35	The graph shows that increasing temperature causes pressure and temperature

Dimension	Indicator Flexibility	Conceptual Meaning	Frequency	Example Student Responses
Perspective	Integration of gas laws	Conceptual perspective vary	38	This case can be explained using Gay-Lussac's law and the ideal gas equation
Self-Knowledge	Reflection on model assumption	Awareness of conceptual limitations	21	Real gases do not always meet the ideal gas assumptions

In the Explanation and Application dimensions, students demonstrated the ability to adapt their problem-solving strategies according to variations in ideal gas variables and conditions. Within the Perspective and Self-Knowledge dimensions, students exhibited deeper conceptual flexibility by connecting multiple gas laws and recognizing the assumptions underlying the models employed. These findings suggest that the observed improvement in flexibility extends beyond procedural competence to encompass conceptual understanding. Students showed the capacity to adapt strategies, integrate multiple forms of representation, and critically reflect on the limitations of the ideal gas model. Such patterns indicate the development of a deeper understanding through mobile-assisted case-based learning.

This study demonstrates that mobile-assisted case-based learning in the context of ideal gas concepts contributes to the enhancement of students' cognitive flexibility, which serves as an important indicator of deep conceptual understanding. The findings are reflected in the improvement of flexibility scores, accompanied by the emergence of diverse problem-solving strategies, the integration of gas-related concepts, and the use of multiple representations in students' responses. These results should be interpreted with caution, as they do not yet establish a strong causal relationship. The observed improvement was not only evident in the shift from lower to higher performance categories but also in students' ability to adapt and switch between problem-solving approaches, integrate various forms of representation (verbal, mathematical, and particulate), and re-evaluate underlying assumptions when applying ideal gas concepts to authentic case contexts. Such findings are consistent with recent studies suggesting that engagement in authentic case-based learning environments can foster higher-order thinking skills by encouraging learners to analyze complex situations, evaluate alternative explanations, and construct more meaningful conceptual connections (Klahr et al., 2019; Schippers & Lange, 2006; Xia & Haas, 2025). Accordingly, this instructional model offers a promising pedagogical approach for fostering students' cognitive flexibility by engaging them in authentic case analysis, multi-representational reasoning, and reflective discussions facilitated through an LMS. Furthermore, the model provides structured scaffolding that supports students with lower prior knowledge, allowing them to progressively develop deeper conceptual understanding and more adaptive problem-solving capabilities.

LIMITATION

This study has several limitations that should be considered when interpreting the findings. First, the use of a one-group pretest–posttest design without a control group limits the ability to establish causal relationships between the mobile-assisted case-based learning intervention and the observed changes in students' creative thinking flexibility. Second, the participants were selected through purposive sampling and consisted entirely of female students from a single science education program at one university, which may limit the generalizability of the findings to broader educational contexts. Third, the study focused exclusively on the flexibility dimension of creative thinking, while other important dimensions such as fluency, originality, and elaboration were not examined. Finally, the investigation was conducted within the context of ideal gas learning over a relatively short intervention period, making it difficult to determine the long-term sustainability of the observed changes. Future studies are encouraged to employ experimental or quasi-experimental designs, involve more diverse participant groups, and examine multiple dimensions of creative thinking across different science topics and learning environments.

CONCLUSION

This study focuses on the impact of mobile-assisted Case-Based Learning (CBL) on students' creative thinking skills, particularly the flexibility indicator as a representation of deep understanding of ideal gas concepts, as well as their learning interest. The findings reveal a tendency toward improved cognitive flexibility following the implementation of mobile-assisted case-based learning. Students demonstrated higher achievement levels and greater adaptability in shifting problem-solving strategies, employing multiple representations (verbal, mathematical, and particulate), and integrating concepts related to ideal gases more conceptually. These outcomes indicate a transition from procedural understanding toward deeper conceptual comprehension. Regarding learning interest, mobile-assisted case-based learning was found to foster positive student engagement. Most students exhibited a high level of interest in the learning process, while only a small proportion showed low interest. The integration of smartphones with a Learning Management System (LMS) provided opportunities for reflection, collaborative discussion, and revision of arguments, thereby supporting the development of more meaningful and interactive learning experiences. Student responses further demonstrated their ability to adapt problem-solving strategies, integrate multiple forms of representation, and critically reflect on the limitations of the ideal gas model.

Mobile-assisted CBL can be recommended as an innovative learning strategy in higher science education because it not only strengthens learning interest but also develops thinking flexibility as the core of deep understanding. To optimize its impact, adaptive scaffolding, consistent formative feedback, and contextual and challenging case designs are required. Further research is recommended to more comprehensively explore the sustainability of student creativity development in digital learning contexts.

AUTHOR CONTRIBUTIONS

TN and LY conceptualized and designed the study and led the implementation of the mobile-assisted case learning. AH and AFH contributed to the development of learning materials, case design, and data collection. MAM conducted data analysis and interpretation of the results. AMF provided supervision, contributed to instructional design, and offered critical revisions to strengthen the integration of technology in learning. All authors reviewed, revised, and approved the final version of the manuscript.

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